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COST IMPACT OF SWITCHED AND NONSWITCHED NETWORKS

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FINAL REPORT
(REVISED)

I. Gershkoff

DECEMBER 1980

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U. S. DEPARTMENT OF TRANSPORTATION
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16. Abstract

This report is an economic analysis of the alternatives of switching and non-switching for approximately 5,000 voice circuits and 1,500 data circuits in the FAA's operational telecommunications network. The switching alternative assumed all circuits to be switched through the 20 continental air route traffic control centers (ARTCCs). An algorithm was developed to calculate the impacts of switching or consolidation on the number of circuits and circuit mileage required in the network. On the basis of an assumed tariff rate, dollar savings resulting from the network reconfigurations were calculated.

The means for performing the analysis was the deployment of the FAA Communications Cost Model. The documents for this study are Report No. FAA-ASP-80-6, "FAA Communications Cost Model User's Guide (Revised)" and Report No. FAA-ASP-80-7, "FAA Communications Cost Model Program Documentation (Revised)."

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METRIC CONVERSION FACTORS

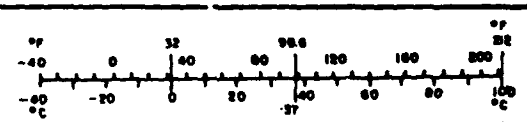
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



SUMMARY

Rapid and reliable communication between pilot and ground and between ground personnel with different air traffic control responsibilities is vital to the accomplishment of the Federal Aviation Administration's air traffic control mission. An important aspect of the FAA operational telecommunications system is a network of about 5,000 voice and 1,500 data circuits used for routine as well as emergency communications. The network has developed over the years into a number of independent voice and data subnetworks, each having a specialized purpose and each growing independently to keep pace with the increasing volume of aircraft operations. Since there is currently little creditable data on the utilization of the FAA's voice circuits, the switching potential was analyzed as a function of circuit utilization. By combining traffic from circuits that are less than 100 percent utilized, there is potential for reducing costs through the elimination of excess capacity.

We conducted an analysis of the circuit network to determine (1) the number of circuits and circuit miles that can be saved through sharing or switching, or both; and (2) the potential dollar savings from such changes. Voice, data, and radio circuits were treated independently for sharing purposes. We developed an algorithm to simulate a voice network whose circuits are switched through the air route traffic control centers (ARTCCs). The economic feasibility of this reconfiguration was dependent on circuit utilization, required grade-of-service, tariff rate, and auxiliary equipment costs. Data circuits were assumed to be multiplexed and routed through the ARTCCs; savings on data circuits would depend only on the tariff rate and equipment costs. Although a few cases of switched radio circuits do exist, radio circuits were not considered primary candidates for sharing and were therefore excluded from the study.

We applied the algorithm to the FAA network of leased voice circuits. Results showed that for the expected circuit utilization of about 0.1 and the required blocking probability of 0.001, switching would eliminate about 1,200 circuits. However, circuit mileage would increase by 275,000 miles because extensive rerouting of circuits through the ARTCCs would be necessary in a switched network. Assuming current tariffs, implementation of this switching algorithm for voice circuits and multiplexing for data circuits would result in a net saving of $23.1 million over the 1980-1990 decade. However, slight changes in utilization or grade-of-service could easily negate these savings. The results for both voice and data circuits were not very sensitive to auxiliary equipment costs over the expected range of these costs.

While this study dealt with costs alone, it should be recognized that there are valid operational requirements for network switching. The major conclusion of this study is that network switching does not provide a significant penalty or savings in circuit costs and is therefore not a major cost reduction option for the FAA under the strict set of architecture constraints analyzed. Although the leased circuit costs for the telecommunications network are currently over $20 million per year, they represent less than 10 percent of the total communications cost. The achievable savings from switching appear to be quite small and would be lost entirely if one or more key parameters were not estimated precisely.

CONTENTS

CONTENTS (continued)

CHAPTER ONE

INTRODUCTION

1.1 *BACKGROUND*

Telecommunications are the central nervous system of the Federal Aviation Administration (FAA). Rapid and reliable communication between pilot and ground and between ground personnel with different air traffic control responsibilities is vital to the accomplishment of the Administration's air traffic control mission and internal business. Operational telecommunications, installed primarily for air traffic control purposes, are used in more than 800 manned facilities. Nearly 3,000 remote telecommunications outlets extend the range and coverage of these facilities so greatly that virtually all aircraft at all altitudes throughout the National Airspace System (NAS) can communicate with appropriate air traffic control facilities. The FAA telecommunications system is the largest operated by any single federal agency other than the Department of Defense.

An important aspect of the FAA telecommunications system is a network of dedicated leased voice and data circuits used for routine as well as emergency communications. In addition to air-ground and ground-ground conversations, some of the circuits carry radar, surveillance, navigation, weather, or flight plan data. The annual expense of using and maintaining these circuits was about $20 million in FY 1979, and the ancillary equipment associated with the circuits cost about $60 million more. In the interest of the safety and efficiency of the NAS, all of the circuits are dedicated private lines. This arrangement is reliable but many of the lines cost as much as $2,000 per year in lease charges.

The network has developed over the years into a number of independent voice and data subnetworks, each having a specialized purpose and each growing independently to keep pace with the increasing volume of aircraft operations. While the existing networks must satisfy the agency's operational needs, significant changes are planned for the future. The FAA is on the threshold of a major recapitalization of its telecommunications system intended to reduce maintenance costs, enhance the productivity of air traffic controllers, improve aviation safety, and consolidate subnetworks. The National Airspace Data Interchange Network (NADIN) will eventually

replace 13 existing data networks; the Voice Switching and Control System (VSCS), currently in the design phase, is planned to facilitate the day-to-day management of voice circuits.

In addition to network consolidation, the FAA is investigating the possibility of sharing some of these circuits in order to reduce costs. Since there are currently little data on the utilization of the FAA's voice circuits, the switching potential was analyzed as a function of circuit utilization. Circuit sharing would be technically feasible only if air safety was not adversely affected and air traffic control procedures were not changed. Whatever consolidation or sharing is done should be virtually transparent to both pilots and controllers.

In order to assess the potential economic benefits of sharing, the Office of Aviation System Plans (ASP) has contracted with ARINC Research to investigate and identify circuits or groups of circuits where switching is feasible. The criteria on which circuit switching will be based are the utilization of the circuit, the traffic volume into each network node, the required grade-of-service, and the costs of auxiliary switching or multiplexing equipment.

1.2 STUDY OBJECTIVES

The primary objective of this study is to develop scenarios under which switching or sharing of leased circuits would be both feasible and cost-effective. The primary variable in such an analysis is the utilization of circuits in the FAA network, a statistic that is estimated with great uncertainty at best, since no hard data exist. As the utilization of a circuit increases, there is less opportunity for savings from sharing because the network is being used more efficiently. Beyond a certain level, no savings are possible. This level will be estimated.

A second important determinant of the level of sharing possible is the criticality of the message being transmitted on the network. For example, a controller handoff is a high priority message, since it is critical to air safety, whereas VFR flight plan data are ordinarily less critical. Circuit switching possibilities will be measured against this variable as well.

1.3 SCOPE

This is primarily a cost study; the only benefits of circuit consolidation considered here are those resulting from a cost reduction. Noneconomic benefits and costs of circuit switching are not considered, such as the simplicity of reconfiguring the network to bypass an inoperative piece of equipment or the need for back-up equipment if a switch line failure should occur. Such factors may increase or decrease the feasibility of switching.

With the time and resources available it was not possible to optimize the switched network. Rather, ARINC Research analyzed a few major reconfigurations in an attempt to identify large potential savings from switching. We therefore avoided analysis on a circuit-by-circuit basis; such detailed analysis would be required only if a new circuit network configuration were to be implemented. It should be clear that this study is not a definitive treatment of the costs and benefits of circuit switching but rather an attempt to show where potential for switching exists and to suggest areas for future analysis of the leased circuit network.

1.4 REPORT ORGANIZATION

In the following five chapters, the report describes the methodology used, details the attributes of the existing leased services network, gives a technical evaluation of the scenarios, examines sensitivities to key variables, and presents major conclusions. Additional detail on some of the supporting data used in this study may be found in the two companion reports, *FAA Communications Model User's Guide* and *FAA Communications Cost Model Program Documentation*, Publication Numbers FAA-ASP-80-6 and FAA-ASP-80-7, both revised April 1980.

Chapter Two provides a description of the technical approach used in the study. It examines available data bases and describes the consolidation algorithms and the communications model, the major tools used in the analysis.

Chapter Three shows the results of a baseline analysis of sharing and consolidation in the FAA leased circuit network. Several alternate network configurations are discussed. Results are presented in terms of changes in the number of circuits and in circuit mileage.

Chapter Four describes the scenarios used with the communications model. The parameters for the baseline case (i.e., the case assuming present technology) are developed.

Chapter Five shows the results of both the baseline analysis and the sensitivity cases. The sensitivity of the cost to each important parameter is analyzed and possible alternatives are discussed.

Chapter Six summarizes the results of the investigation and presents conclusions based on the economic evaluation of the alternatives considered in the study.

CHAPTER TWO

TECHNICAL APPROACH

2.1 INTRODUCTION

This chapter describes the methodology used by ARINC Research Corporation to develop scenarios for circuit sharing in the FAA network. The goal of this analysis is to determine (1) the number of circuits and circuit miles that can be saved through sharing, (2) the potential dollar savings from sharing, and (3) the effect on (1) and (2) of new technology planned for the 1980s.

The procedure for developing these results consists of several steps, each of which is described in subsequent sections. First, the current network is divided into homogeneous groups of circuits that can be independently evaluated for sharing: voice, data, and radio circuits. It is technically difficult to carry communications of different kinds (e.g., voice and data) on the same circuit. These groups are further discussed in Section 2.3.

Second, it is necessary to determine whether each circuit meets the criteria of feasible sharing, which are described in Section 2.4. The above two steps should be sufficient to classify each circuit and eliminate from consideration those that are poor candidates for switching.

The third step is to calculate the effects of switching or sharing on the circuit network configuration. An algorithm was applied that would calculate the minimum number of circuits between two points required to satisfy a given traffic and grade-of-service constraint. Section 2.5 describes the method of assessing changes in network configuration and the algorithm for calculating the number of circuits required.

Effects of the new technology systems of the 1980s can be evaluated with a computer-based communications cost model designed to show the cost impact of changes in the technical or regulatory framework of the FAA. This model is the subject of Section 2.6. Some of the circuit sharing algorithms described in this chapter have been incorporated into this model. Specific scenarios can be devised that would analyze the effects of sharing various groups of circuits, both with and without the new-technology systems planned for the 1980s. More detail on the structure and application of the communications model may be found in the reports *FAA Communications Cost Model Program Documentation* and *FAA Communications Model User's Guide*.

2.2 OVERVIEW OF FAA CIRCUIT NETWORK

The primary source of data for this study is an extensive data base of leased circuits and leased equipment maintained by the Transportation Systems Center in Cambridge, Massachusetts. The data base contains approximately 18,000 records of FAA circuits. A subset of each record was separated into a smaller data base containing such information as tariff, location of the end-points, mileage, and circuit use. Table 2-1 shows the information found in a sample record. While there are occasional errors or blank fields on some records, most of the data are accurate enough to permit the circuits to be classified and grouped according to common attributes.

Table 2-1. AVAILABLE INFORMATION FROM TSC DATA BASE

Identifier	Explanation	Values
CID	Circuit number	Integers (1 to 18,132)
CODE	Circuit type code	Four characters
ND	Number of drops	Integers (2 or greater)
BPS	Bits per second	Integers (0 = not a data circuit)
EMRC	Equipment cost per month	Dollars
TMRC	Telpak cost per month	Dollars
IMRC	IXC cost per month	Dollars
TPKM	Telpak mileage	Miles
IXCM	IXC mileage	Miles
FV	"From" V coordinate	Four-digit integer
FH	"From" H coordinate	Four-digit integer
FR	"From" FAA region	Two-character code
FFC	"From" facility type code	Integers (1 to 303)
FLID	"From" facility identifier	Three-character code
TV	"To" V coordinate	Four-digit integer
TH	"To" H coordinate	Four-digit integer
TR	"To" region	Two-character code
TFC	"To" facility type code	Integers (1 to 303)
TLID	"To" facility identifier	Three-character code

Figure 2-1 shows the structure of the FAA communications network. The diagram shows the major communications links among the operating units. The system may be thought of as the union of 20 smaller subnetworks, each

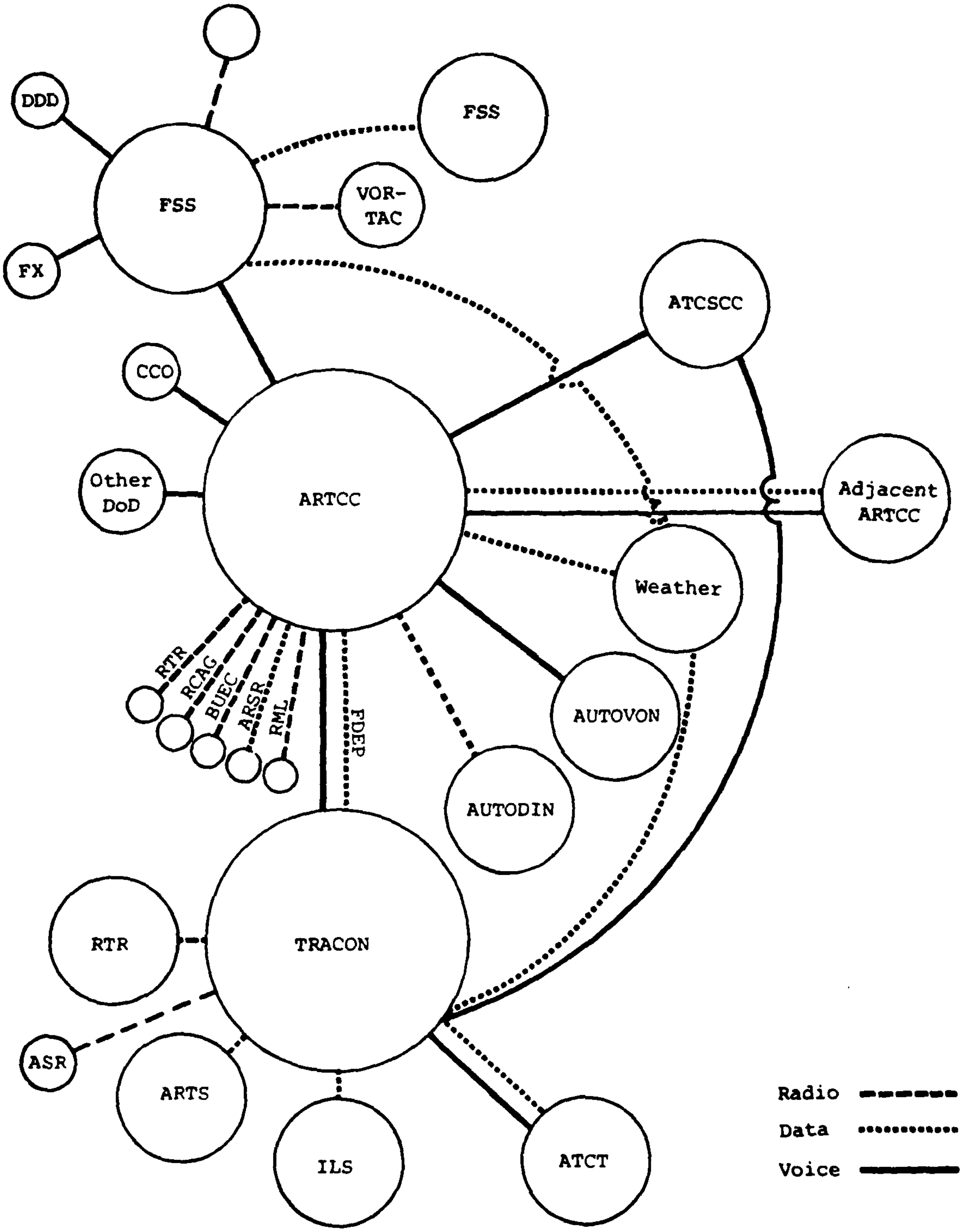


Figure 2-1. STRUCTURE OF FAA COMMUNICATIONS NETWORK
(See next page for glossary of acronyms.)

GLOSSARY OF ACRONYMS USED IN FIGURE 2-1

ARSR	- Air route surveillance radar
ARTCC	- Air route traffic control center
ARTS	- Automated radar terminal systems
ASR	- Airport surveillance radar
ATCSCC	- Air traffic control system command center
ATCT	- Air traffic control tower
AUTODIN	- Automatic data network (DOD)
AUTOVON	- Automatic voice network (DOD)
BUEC	- Back-up emergency communications
CCO	- Command communications outlet
DDD	- Direct distance dialing
FDEP	- Flight data entry and printout
FSS	- Flight service station
FX	- Foreign exchange
ILS	- Instrument landing system
Other DOD	- Other Department of Defense facilities
RCAG	- Remote communications air/ground
RML	- Remote microwave line
RTR	- Remote transmitter/receiver
TRACON	- Terminal radar approach control
VORTAC	- VOR/TACAN, a navigation beacon and communications outlet

with an air route traffic control center (ARTCC) at its hub. On the average, there are about 15 flight service stations (FSSs) and 20 towers within the jurisdiction of a center. Although these numbers vary, there is no substantial difference from center to center in the nature of the communications links among the operating units. With the exception of voice and data links between centers, there is little need for communications between facilities assigned to two different ARTCCs.

Nearly all of the communications links shown in Figure 2-1 terminate in or connect with an ARTCC. This suggests that the centers would be convenient central facilities through which communications traffic could be switched; this possibility will be discussed further in Section 2.4.

2.3 CLASSIFICATION OF FAA CIRCUITS

In order to assess the possible savings from circuit sharing and switching, it is necessary to determine which circuits are compatible for sharing purposes. Although it is technically feasible to design a switch that can accommodate, for example, both a voice and a data circuit, interface problems would likely negate any savings resulting from the reduced circuitry. Thus, it is important to divide the circuit network into homogeneous subnetworks that can be analyzed individually.

A simple yet useful way of classifying circuits for this purpose is to label them as voice, radio, or data. Voice circuits are ground-ground voice-grade private lines used by air traffic personnel. These are indicated by solid lines in the diagram of Figure 2-1. They are routinely used for controller handoffs, flight plan data, or any other type of message that needs to be sent. Data circuits, which comprise about 10 percent of the total, are used for computer-to-computer or computer-to-console communications. These are indicated by dotted lines in the diagram. Radio circuits are those which interface with an air-ground communications system. Since VHF communications are limited by line-of-sight coverage, it is often necessary for the ARTCC to install transmitting and receiving equipment in the remotest parts of its jurisdiction and bring the signal back to the center via private line. Radio circuits are indicated by dashed lines in Figure 2-1.

The significance of this breakdown is that it will be difficult to consolidate or switch groups of circuits containing more than one of these three circuit types. For the purpose of analyzing switching potential, the FAA network may be visualized as three independent communications networks sharing common termination points. It is implicitly assumed that there is no interaction between circuits of different types.

2.4 POTENTIAL FOR CIRCUIT SHARING

There are several methods of implementing circuit sharing that might be cost-effective under the proper circumstances. The most effective method to use depends on the circuit type (voice, radio, or data),

characteristics of its usage, and characteristics of the other circuits with which it would be shared. These issues are discussed in this section. The most obvious way to reduce the number of circuits is to cut excess circuit capacity between a pair of facilities. For example, there may be a separate, dedicated voice circuit for each possible pair of controller positions across a center boundary. Since each circuit is assumed to be lightly loaded, it may be cost-effective to introduce switching equipment that will select an available circuit and route the call through to the other center, where an analogous piece of hardware will select the proper controller position to ring.

The problem with this scheme is that it reduces the number of circuits below the number of potential pairs of users of those circuits. This introduces a probability, however small, that all circuits will be busy when an additional controller needs a line. Even for the most critical of messages, however, a feasible back-up procedure can probably be developed. In the current system, in spite of the dedicated lines that eliminate the possibility of a busy circuit, there remains the possibility that the receiving controller is making a call of his own. An override capability currently exists whereby the controller may cut into another controller's communications in order to convey a critical message. For the purpose of this analysis, it will be assumed that a similar procedure could be implemented for a switched circuit network.

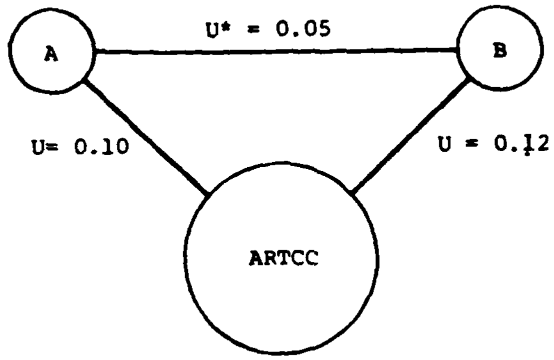
Given the average circuit utilization and the required grade-of-service (expressed as a maximum probability of a blocked call), the number of circuits required can be calculated from formulas used in queuing analysis.

A second possible way to reduce the number of circuits is to switch through a remote facility. For example, there may be a need for communication between two towers, each of which must also communicate with a center. If the message traffic from tower A to tower B can be routed through the center, the circuit from tower A to tower B can be eliminated. This will increase the traffic along the trunks from A to the center and from B to the center, but if the utilization is low enough along these trunks, this increase will have minimal impact on the loading of these circuits. Figure 2-2 represents such a switching.

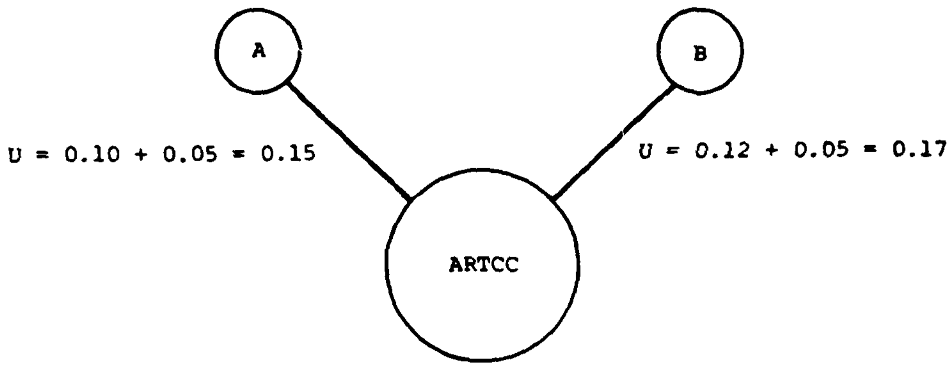
A final method for circuit reduction is to share facilities with another government agency; for example, the FAA already receives weather data from NOAA and various Defense Department installations. Air traffic control for military flights is also tied in with the FAA communications system. Other agencies needing access to FAA-held information may find it profitable to enter into similar arrangements. This type of sharing may be workable if the outside government agency and the FAA both need data from the same source. This is a relatively rare occurrence; consequently, we do not think that sharing circuits with other agencies can be a major source of savings.

Consolidation of voice circuits most likely would be combined with switching. Particularly in the underutilized, high-capacity trunk groups, a reduction in voice circuits, with a corresponding increase in utilization, might hardly be noticeable.

Before Switching:



After Switching:



*U = circuit utilization.

Figure 2-2. SWITCHING THROUGH REMOTE FACILITY

Data circuits are used for computer-to-computer or computer-to-terminal transmission of information. Each circuit belongs to one of several subnetworks that differ substantially in the quantity of data transmitted, the message priorities, and the data bit rate. All of the data circuits were found to be either low speed circuits (120 bits per second or less) or fairly high speed circuits (1,200 bits per second or greater).

Underutilized data circuits can be combined through multiplexing, with or without switching. Multiplexing is a process that combines bits from several lower speed messages on a higher speed data line. At the other end of the line, the signals are distributed to the proper terminals. Unlike voice circuits, data circuits combined in this way will not introduce any probability of blocking; each circuit becomes more efficient by sharing its excess bandwidth. The National Airspace Data Interchange Network (NADIN) system, currently under development, will use a combination of multiplexing and switching to consolidate data circuits.

Radio circuits are those connecting a remote center air/ground (RCAG), a remote transmitter-receiver (RTR), or a remote communications outlet (RCO) with an FSS, center, tower, or terminal radar approach control (TRACON). They carry air-ground voice communications and are one of the most vital communications links in air traffic control. In the interest of air safety, each line must remain open at all times; neither pilots nor controllers could tolerate the possibility that communication could be delayed as a result of switching. Furthermore, some of the busier frequencies (e.g., approach control) have very high utilization anyway. Although opportunities do exist to switch some light-traffic, low-priority circuits in the network, we do not think that switching is, in general, a feasible option for air-ground circuits. Since this is not a circuit-by-circuit analysis, we have chosen not to include these circuits in any of the switched configurations analyzed.

Of the remote facilities through which circuits can be switched, the air route traffic control centers (ARTCCs) are the most logical choice. Although it is desirable to keep the number of switching centers small enough to take advantage of economies of scale in switching equipment, the number should be large enough that the circuits between the facilities and the switching centers are not inordinately long. Since most facilities already have at least one circuit to the nearest ARTCC, the ARTCCs could serve as hubs of a switched network with the least impact on the current network. This conclusion was reached fairly early in the development of the FAA's VSCS program.

2.5 SWITCHING ALGORITHM

The criteria developed in the previous sections were used to formulate algorithms for voice and data circuits to measure the potential for circuit switching and consolidation. The calculation algorithms are discussed in this section.

The logic of this model is shown in Figure 2-3. Each circuit was first classified as voice, data, or radio. If the circuit terminated either in the System Command Center (SCC) or in the Kansas City meteorological center (WMSC), we considered it not eligible for switching because these circuits will be switched in the National Airspace Data Interchange Network (NADIN) system. Multiple drop circuits, numbering about 8.5 percent of the total, were also not considered for switching because of the complexities of searching for and analyzing intermediate drop points. Radio circuits were not switched, for reasons described above.

In considering each circuit, we maintained and updated a list of all possible pairs of termination points. If we found that at least one end of a circuit was a center, we added to the list a demand for a channel for that particular pair of facilities. If neither facility was a center, we added a demand for a circuit between each of the two facilities and its closest center. If the two centers were not the same, we added a third circuit to connect them.

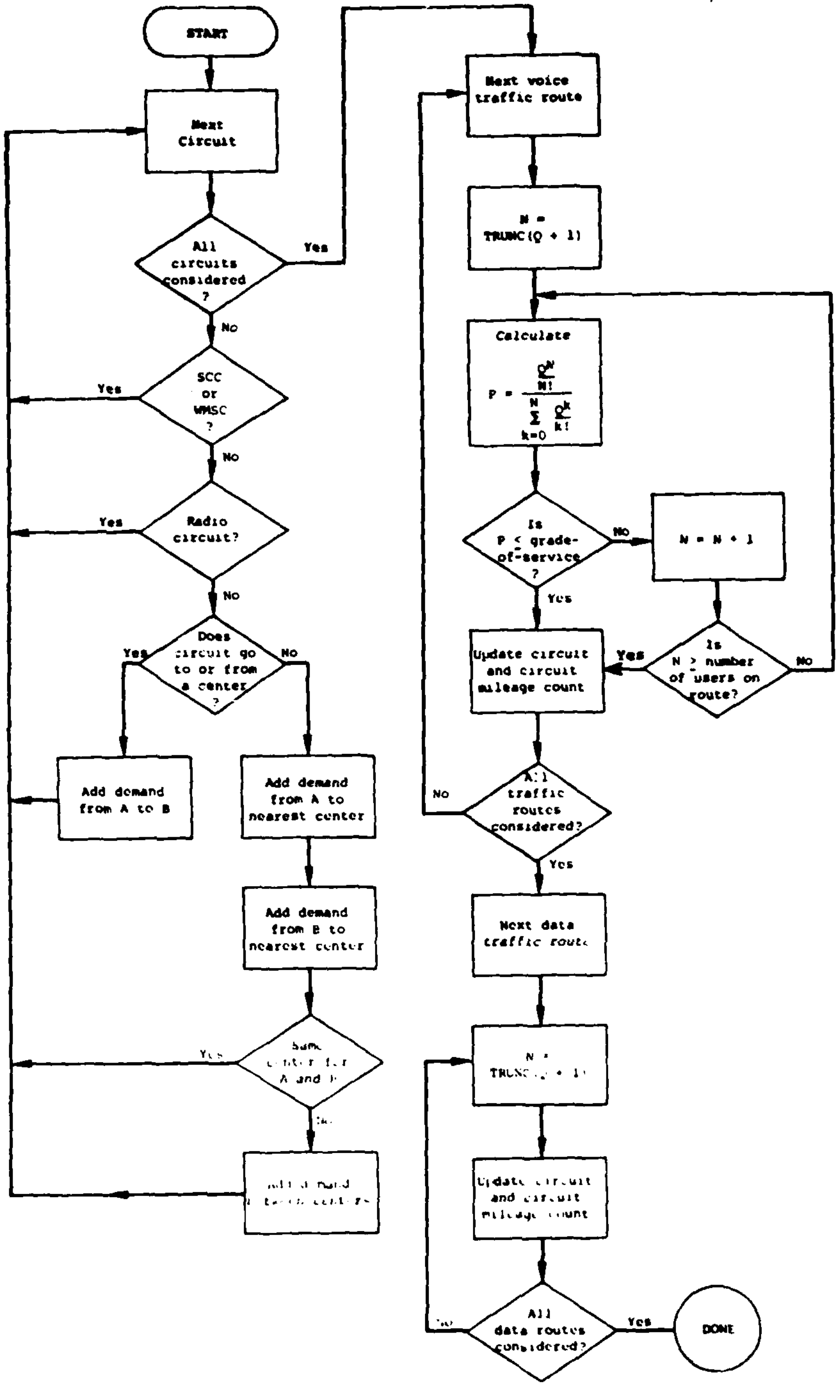


Figure 2-3. FLOWCHART OF SWITCHING ALGORITHM

After all circuits have been treated in this way, the number of voice circuits required to satisfy a given grade of service constraint can be calculated with the standard equation from queuing theory:

$$P_B = \frac{\frac{\varrho^N}{N!}}{\sum_{k=0}^{N} \frac{\varrho^k}{k!}}$$

where

P_B = probability of blocked call

ϱ = traffic in erlangs

N = number of circuits available

The probability of a blocked call is a measure of the grade-of-service. The lower the probability, the better the grade-of-service. Since this equation yields the grade-of-service as a function of traffic and the number of circuits, it is necessary to substitute into the equation the amount of traffic as a first guess and increase the number of circuits one at a time until the grade-of-service criterion is met.

An implicit assumption of the above formula is that call-holding times are exponentially distributed. While this may not be strictly true, we felt that this equation was an appropriate tool to use for this model. Since we are not attempting to design the network on a circuit-by-circuit basis, but rather to look at the overall impact of switching, we believe that any errors introduced by violating the call-holding time assumption would be small.

A different algorithm applies to data circuits. We assume that data circuits are multiplexed if two or more users share a line and that the bits-per-second rates of the users may be added until the capacity of the data line is reached. This capacity is taken to be 1,200 bits per second (bps). Although a high-speed data line is capable of 2,400 bps, we assume only half this figure usable in order to minimize co-channel interference and account for signal distribution. Handled in this way, without switching, there will be no utilization or grade-of-service constraint. Since each computer or other data equipment "sees" a dedicated line connecting to it, there is no possibility of a blocked call.

At this point the simulated development of the switched network configuration is complete; it is only necessary to aggregate the number of circuits and their mileages to compare with the status quo network. It should be pointed out that the network configuration described above results from the application of a relatively simple macrolevel algorithm to the entire circuit network. Different savings might be achieved by optimizing the network on a circuit-by-circuit basis. Such an analysis is believed to be inappropriate in a general model and would not affect aggregate leased circuit costs significantly.

2.6 EXTENSION TO COMMUNICATIONS MODEL

The network switching algorithm described in Section 2.5 can provide a detailed assessment of the effects of switching on FAA circuit terminations and circuit mileage. By itself, however, this algorithm does not calculate circuit or other costs and could not assess the impact of new technology systems on FAA costs. The communications cost model is not structured to optimize the network design by evaluating the feasibility of switching on a circuit-by-circuit basis. Accordingly, this switching algorithm was condensed to operate on groups of circuits rather than individual circuits and was incorporated into the communications model. This refinement was added as a direct consequence of this study.

The communications model does not have access to circuit-by-circuit records, such as exist in the TSC data base. To save storage space and computation time, all circuits were categorized according to different characteristics; parameters associated with each category can be accessed and modified, depending on the type of analysis being performed.

The circuit cost algorithms within the communications model are suitable for evaluating alternate network configurations with the advent of new-technology systems such as DABS, ETABS, VSCS, and AFSS.

CHAPTER THREE

BASELINE SWITCHING ANALYSIS

3.1 INTRODUCTION

This chapter shows the results of applying the network switching algorithm described in the previous chapter to the current FAA leased circuit network. This algorithm is a means of simulating a network reconfiguration resulting from switching voice circuits and multiplexing data circuits. The air route traffic control centers (ARTCCs) serve as the message routing hubs of both the voice and data networks. Radio circuits, as previously discussed, remain untouched.

The number of circuits required between any two nodes in a switched system for voice is a function of the utilization per circuit and required grade-of-service. If the utilization is low, say 0.01, then that traffic could be easily added to another circuit without seriously affecting its traffic load, thereby eliminating a circuit. However, if the utilization is high, say 0.70, then that circuit is already being used fairly efficiently. Attempts to eliminate that circuit by offloading its traffic onto a second circuit may fail because the additional traffic load is likely to overload the circuit. Thus, switching will be more feasible economically at low circuit utilizations.

Grade-of-service is defined as the probability that a call cannot be completed because all circuits are busy. The lower the grade-of-service value, the better the service. At higher values for this variable, fewer circuits are required to guarantee that the assigned grade-of-service constraint will be met; however, the circuits will all be busy more of the time.

Cases were developed for voice circuits for assumed utilization rates of 0.1, 0.2, 0.3, 0.4, 0.6, and 0.8. For each of these values, cases were run for grade-of-service values of 0.001, 0.004, 0.01, 0.04 and 0.1. This represents a probable range of service grades useful in the FAA. The 0.1 figure might be all that is required for a noncritical weather inquiry, while 0.001 would be typical of a critical message, such as a center-to-center nonradar handoff. Though it is true that such circuits must be nonblocking according to the Air Traffic Service operational requirements, a feasible back-up procedure or operational override would probably be developed so that the standard would be met.

For each of these cases a comparison was made of the number of circuits and the circuit mileage with those of the present unswitched network. These two variables were chosen because the current tariffs are principally dependent on circuit terminations and mileage. If both the number of circuits and the mileage were less than those of the present network, then switching was considered feasible in terms of cost. If one value was greater and the other less, the feasibility would depend on tariff rate structure. The Telpak private line tariff was used as the basis of evaluation of all switched configurations.

From an evaluation of these cases it will be possible to identify break-even points, based on utilization and grade-of-service, for which switching would result in a reduction in the cost of leased services. A parametric approach is necessary because, for the FAA network, hard data on utilization and required grade-of-service do not exist. However, it will be possible to assess the sensitivity of the results to these parameters and identify a range of values over which positive savings can be achieved.

One other critical factor that must be considered is the cost of switching equipment. This equipment is needed to sense that service is being requested from a service terminal, to find an idle circuit, and to make the connection. The equipment cost must be subtracted from the saving calculated on the basis of utilization and grade-of-service alone.

The algorithm for data circuits is somewhat different. Data circuits are assumed to be multiplexed without switching. Therefore, there is no probability of a busy signal, and the grade-of-service and utilization criteria do not enter into the analysis. Treatment of data circuits is discussed further in Section 3.4.

The next section describes some of the characteristics of the present circuit network, including circuits that interface with those of other government agencies. Subsequent sections in this chapter analyze the voice and data networks according to the network algorithms in Chapter Two. The impact of auxiliary equipment is factored into the estimate of possible savings resulting from switching or multiplexing. Finally, an estimate is made of current values of utilization and required grade-of-service in order to forecast economic savings resulting from switching or multiplexing.

3.2 CURRENT NETWORK STATISTICS

Table 3-1 shows the number of circuits and the circuit mileage for the three circuit types in the FAA network. The figures do not include zero-mileage circuits connecting equipment in the same building or in adjacent buildings; these circuits, numbering about 7000, are priced as part of the equipment in which they terminate, and are too short and too inexpensive to be considered as candidates for switching.

The remaining circuits are primarily priced under the Telpak tariff, which is modeled at $43.30 per termination per month (there are at least two terminations per circuit) plus $0.50 per mile per month. This tariff

Table 3-1. PRESENT FAA CIRCUIT NETWORK (NONSWITCHED)		
Circuit Type	Number of Circuits	Circuit Mileage
Point-to-point voice	4,911	352,282
Point-to-point data	1,496	231,270
Point-to-point radio	4,004	434,456
Subtotal	10,411	1,018,008
Multiple Drop	974	434,158
Total	11,385	1,452,166

is about half the commercial private line rate and is available to the FAA through its business arrangement with the Defense Communications Corporation (DECCO). Applying this tariff to the figures in Table 3-1 yields an annual cost of $21.5 million. This figure is a little high (the actual figure for FY 1979 was about $19 million) because not every circuit is actually priced according to the Telpak tariff, but it is a good indication of leased circuit costs. The results of this analysis are not sensitive to this difference.

About seven percent of all leased circuits have at least one termination in a facility outside of the FAA jurisdiction. Analysis of the TSC data base shows that all of them are linked to facilities of the Department of Defense, the Coast Guard, or the National Weather Service. These circuits are important because they indicate outside government agencies that (1) need to exchange information with FAA on a real-time basis, (2) need communications services in the course of their normal operations, and most important, (3) might be willing to enter into communications resource sharing agreements with the FAA.

Table 3-2 shows a breakdown of these 1129 circuits. Zero-mileage circuits between nearby buildings or equipments are included in these figures. Approximately 69 percent of the circuits interface with military facilities in all branches of the armed services ("military" denotes the Army, Navy, Air Force, Marines, Coast Guard, and Air National Guard).

3.3 VOICE CIRCUIT SWITCHING

This section shows the results of applying the switching algorithm to the voice network. Results are shown in Table 3-3. For each of the combinations of utilization and grade-of-service, the table shows the changes in (1) the number of circuits required, (2) circuit mileage, and (3) assuming a tariff of $86.60 + $0.50 per mile, the change in annual cost before switching equipment costs are considered; these costs are discussed in Section 3.5.

The number of circuits is reduced for all grades-of-service if utilization is 0.2 or less, and for the 0.3 and 0.4 cases it is reduced for the

Table 3-2. NON-FAA CIRCUIT TERMINATIONS	
WMSC to Military	2
Tower to Military	311
FSS to Military	143
Center to Military	165
Military to Military	55
Tower to AUTOVON/AUTODIN	13
FSS to AUTOVON/AUTODIN	8
Center to AUTOVON/AUTODIN	64
Other AUTOVON/AUTODIN	19
WMSC to Weather	31
Tower to Weather	203
FSS to Weather	76
Center to Weather	9
Military to Weather	5
Weather to Weather	25
Total	1129

poorer grades-of-service. For the two highest utilizations the number of circuits is greater than for the baseline system; this is expected, since high utilization violates one of the principal assumptions on which the switching algorithm is based.

What is somewhat surprising is that the circuit mileage increases in every case. This could occur either because utilization is too high, as before, or because many of the circuits being saved are short connections between remote facilities. For example, assume that traffic between two FSSs on a circuit 100 miles long is to be switched through the nearest center. If the additional traffic to and from the center creates a need for an additional circuit 500 miles long, net circuit mileage will increase. The increase in mileage must be considered in combination with the decrease in the number of circuits. Depending on the tariff rate used to price the circuits, an increase in mileage costs may be desirable if it is more than offset by a decrease in circuit termination costs.

Figure 3-1 shows a plot of the number of circuits saved as a function of utilization for grades-of-service of 0.1 and 0.001. The curves for the other grades would fall between these two. The shape of the curves is a function of grade-of-service. For a very poor grade (GOS = 0.1) the curve would essentially be a straight line, since a given increase in utilization would require a constant quantity of circuits to accommodate it. At very

Table 3-3. SWITCHING RESULTS FOR VOICE NETWORK					
Utilization	Changes by Grade-of-Service (GOS)				
	GOS 0.1	GOS 0.04	GOS 0.01	GOS 0.004	GOS 0.001
Change in Number of Circuits					
0.1	-2591	-2254	-1774	-1533	-1223
0.2	-1811	-1293	- 744	- 504	- 192
0.3	- 989	- 430	+ 75	+ 338	+ 613
0.4	- 278	+ 306	+ 803	+1041	+1290
0.6	+1039	+1532	+1935	+2084	+2246
0.8	+2140	+2423	+2674	+2761	+2841
Change in Thousands of Circuit Miles					
0.1	+ 58	+ 112	+ 188	+ 226	+ 275
0.2	+ 185	+ 249	+ 335	+ 371	+ 418
0.3	+ 287	+ 372	+ 447	+ 486	+ 525
0.4	+ 383	+ 473	+ 543	+ 575	+ 607
0.6	+ 565	+ 631	+ 680	+ 695	+ 711
0.8	+ 702	+ 732	+ 759	+ 769	+ 778
Change in Circuit Expense (Thousands of Dollars)					
0.1	-2345	-1670	- 716	- 237	+ 379
0.2	- 772	+ 150	+1237	+2073	+2308
0.3	+ 694	+1785	+2760	+3267	+3787
0.4	+2009	+3156	+4092	+4532	+4983
0.6	+4469	+5378	+6091	+6335	+6600
0.8	+6435	+6910	+7333	+7483	+7620
Note: + indicates an increase over the values from the non-switched network.					

good grades-of-service, the curve would fall off sharply until it met the constraint that the total number of circuits cannot exceed the number of network users; at this point, it would level off. Theoretically, curves for all grades-of-service converge at utilizations of 0 and 1. At very low utilizations, regardless of service grade, switching works very well, since only one circuit is needed to accommodate traffic between each facility and the nearest center. At very high utilizations, switching introduces unnecessary circuits because there is no opportunity to share. Sensitivity to grade-of-service, if utilization remains constant, can be inferred by examining the difference between the two curves. It appears to reach a maximum at a utilization of about 0.2-0.3.

Figure 3-2 shows the same plot for circuit mileage. The curves exhibit similar characteristics; they converge at utilizations of 0 and 1, and they show maximum sensitivity to grade-of-service for utilization in the 0.2-0.3 range.

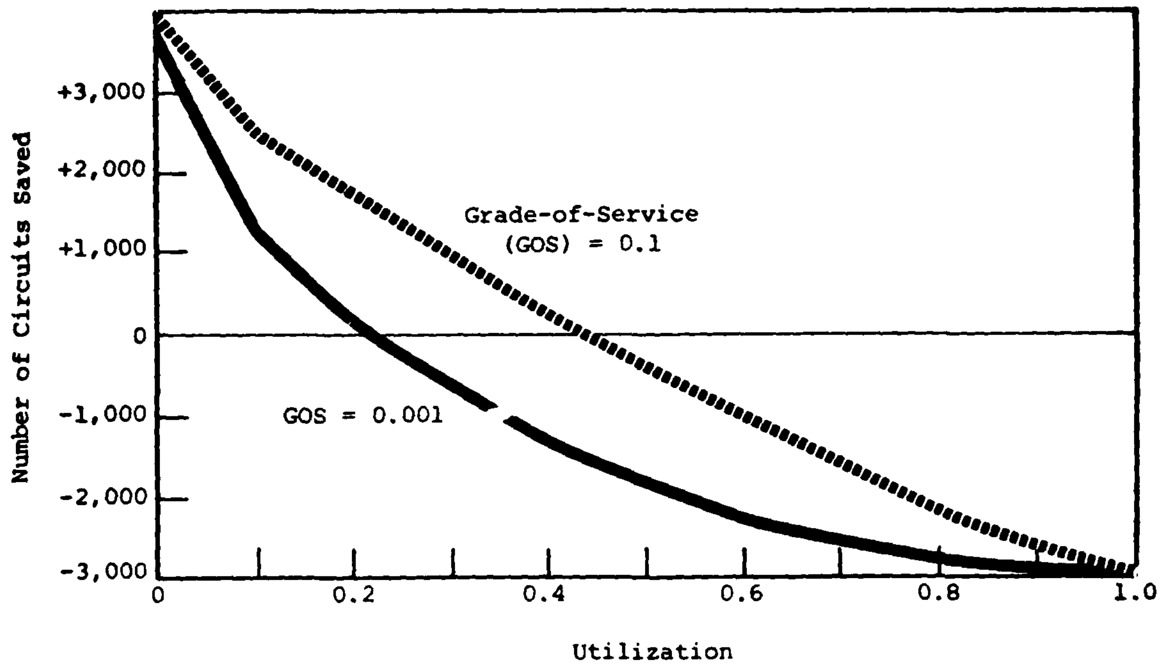


Figure 3-1. CIRCUITS SAVED AS A FUNCTION OF BASELINE UTILIZATION

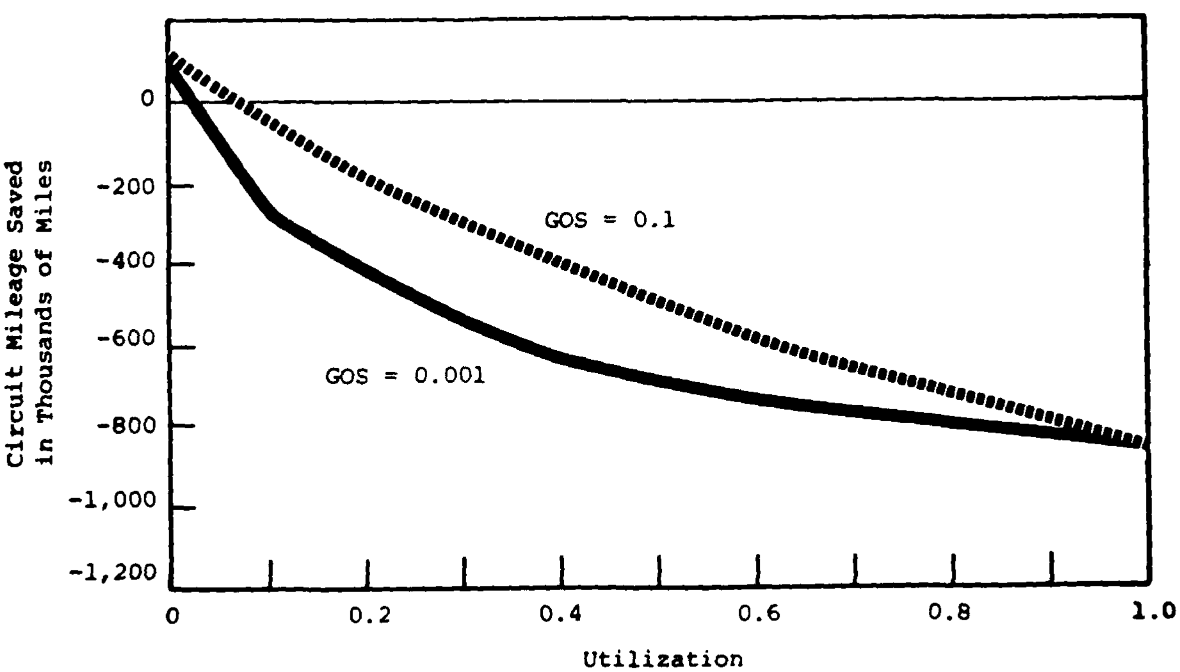


Figure 3-2. CIRCUIT MILEAGE SAVED AS A FUNCTION OF BASELINE UTILIZATION

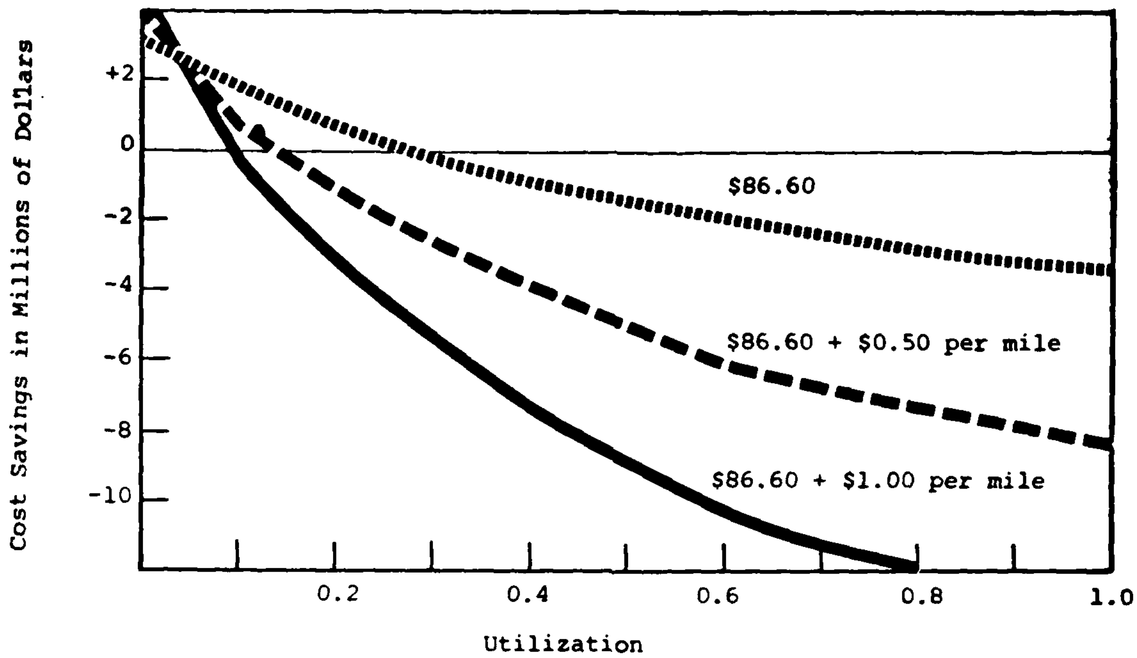


Figure 3-3. SENSITIVITY OF DOLLAR SAVINGS TO CHANGES IN TARIFF RATE (GRADE-OF-SERVICE = 0.01)

Figure 3-3 shows the sensitivity of the dollar savings to changes in the tariff rate. Proportional increases in the termination and mileage components of the tariff rate will result in a proportional change in the dollar savings; the relative standing of each of the categories will not change. A more useful scenario is to vary just one of the two components, in this case the cost per circuit mile. Here the curves cross at that point where the mileage saved is zero, corresponding roughly to a utilization of about 0.05 and a grade-of-service of 0.01. If the termination charge was varied rather than the mileage charge, the curves would have a similar shape, and they would intersect at that point where circuits saved are zero.

Figure 3-4 summarizes these results for voice circuits. The curves show the locus of points under each of the assumed tariff rates for which the savings due to switching would be zero. All points to the left of the curve would result in positive savings; all points to the right in negative savings. For the nominal tariff, average circuit utilization in the current FAA network must be below 0.25 to give switching a chance of economic feasibility. This figure ignores the impact of auxiliary equipment costs, which will be discussed in a later section.

3.4 DATA CIRCUITS

Data circuits differ from voice circuits in the way they are combined to effect savings. Voice-grade lines subject to the Telpak tariff are capable of carrying up to 9,600 bits per second (bps) of data; yet the FAA

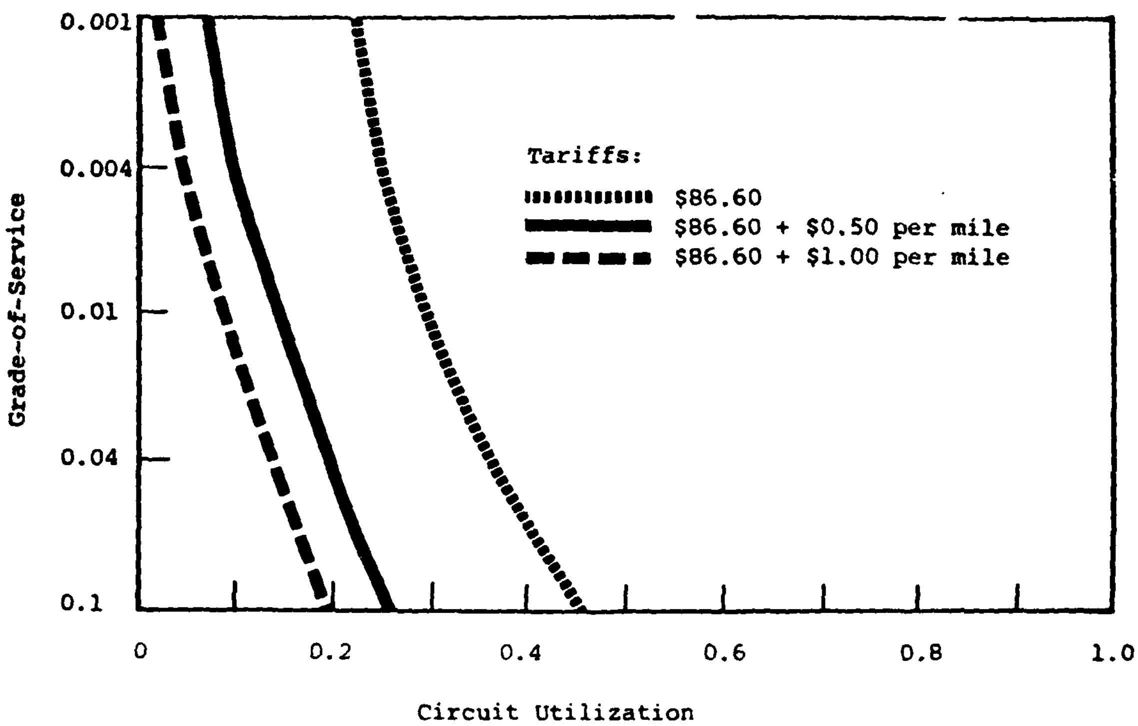


Figure 3-4. LOCUS OF BREAK-EVEN POINTS AS A FUNCTION OF TARIFF RATE

has many data circuits that carry 10 bps teletype data. Equipment is available that can combine the messages of several such lines, transmit them on a single voice grade line, and redistribute them at the other end. This is called multiplexing. If multiplexing were implemented, the need for many underutilized data circuits (underutilized in terms of data capacity, not necessarily underutilized over time) would be eliminated. Furthermore, since the data transmission system would be unchanged from the point of view of each terminal user, there would not exist the problem of a blocked call, as is the case with voice transmission. Thus, an assumption of the model is that data will not be switched, but multiplexed; therefore, the utilization and grade-of-service variables are not meaningful. Multiplexing increases the risk of simultaneous circuit outages; however, high-speed data circuits (1,200 bps or greater) would not be combined through multiplexing and would remain dedicated lines.

As a result of multiplexing, the number of data circuits dropped from 1,496 in the baseline to 1,028, a saving of 468 circuits. This saving is partially offset by an increase in circuit mileage from 231,270 to 247,292, a gain of 16,022 miles. At the assumed tariff rate of $86.60 + $0.50 per mile, this reconfiguration would result in an annual saving of $390.000. As in the case of voice circuits, it is likely that data circuit mileage would be reduced, and the total circuits switched decreased if a decision whether to switch was made on a circuit-by-circuit basis.

The feasibility of data circuit switching is less sensitive to the tariff than that of voice circuit switching. Figure 3-5 shows the changes

in savings that would result from a change in the mileage component of the tariff. The mileage charge would have to go to about $2.50 per mile to negate the savings from data switching. These results ignore switching and multiplexing costs, which are discussed in the next section.

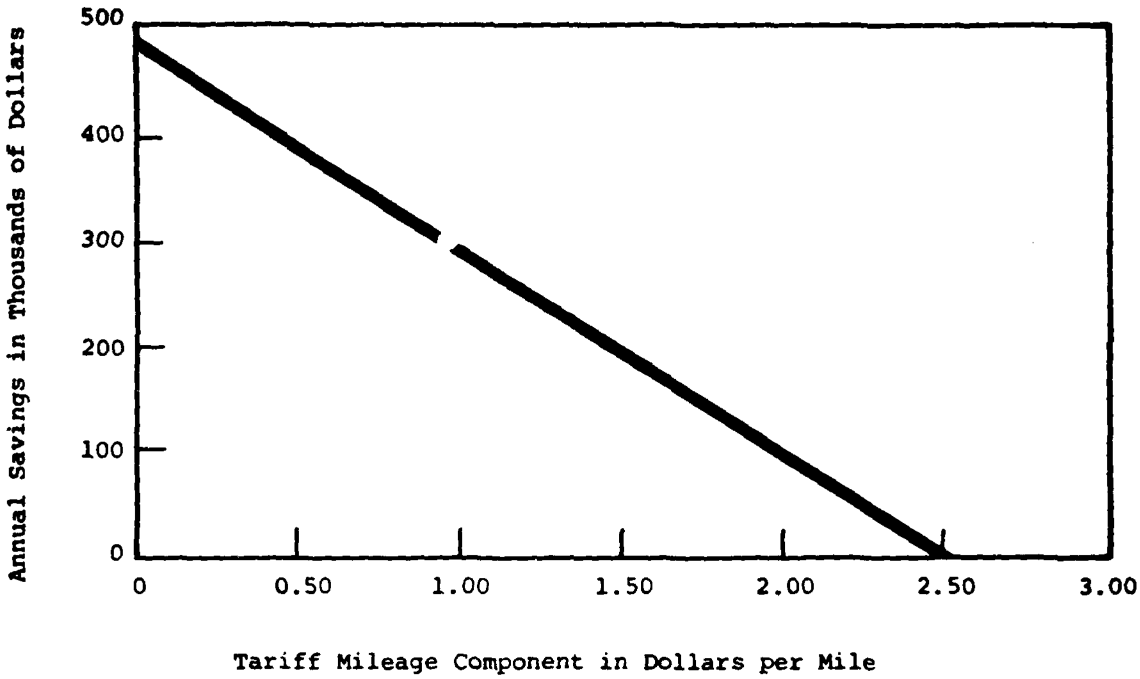


Figure 3-5. COST SAVINGS VERSUS TARIFF FOR DATA SWITCHING

3.5 EFFECT OF EQUIPMENT COSTS

Up to this point, the feasibility of switching or multiplexing has been analyzed without regard to equipment cost. In any such network it will be necessary to procure and maintain switching or multiplexing equipment. It should be noted that the planned introduction of the Voice Switching and Control System (VSCS) in the 1980s will provide a switching capability at no additional cost. The analysis in this section, however, represents the introduction of switching without VSCS. The analysis up to this point would be valid in considering a case where switching equipment costs are zero or nearly so.

For the purpose of this analysis these costs can be modeled as a fixed amount per circuit for both capital and maintenance. If standard techniques are used for amortizing capital purchases, the F&E switch cost for the voice network can be converted into an annual cost that, together with the O&M

cost, can be subtracted from the potential savings computed earlier in this chapter. Assuming a 10 percent value of money and a 10-year equipment life, the annual payment will be 16.27 percent of the principal.* If the equipment life is 15 years, the annual payment will be 13.15 percent of the principal. These percentages can be used to calculate the break-even equipment costs needed to make switching feasible.

Figure 3-6 is a plot of maximum equipment cost per circuit as a function of utilization for three grades-of-service in the voice network. The figures are for a 10-year equipment life, but the 15-year figures can be calculated by multiplying by 16.27/13.15. Switch costs are assumed to be on the order of $500-$1,000 per circuit; therefore, at a utilization of 0.07 or less, the switched network will be economically feasible regardless of the grade-of-service. If utilization exceeds 0.25, it will not be feasible regardless of grade-of-service or switch cost.

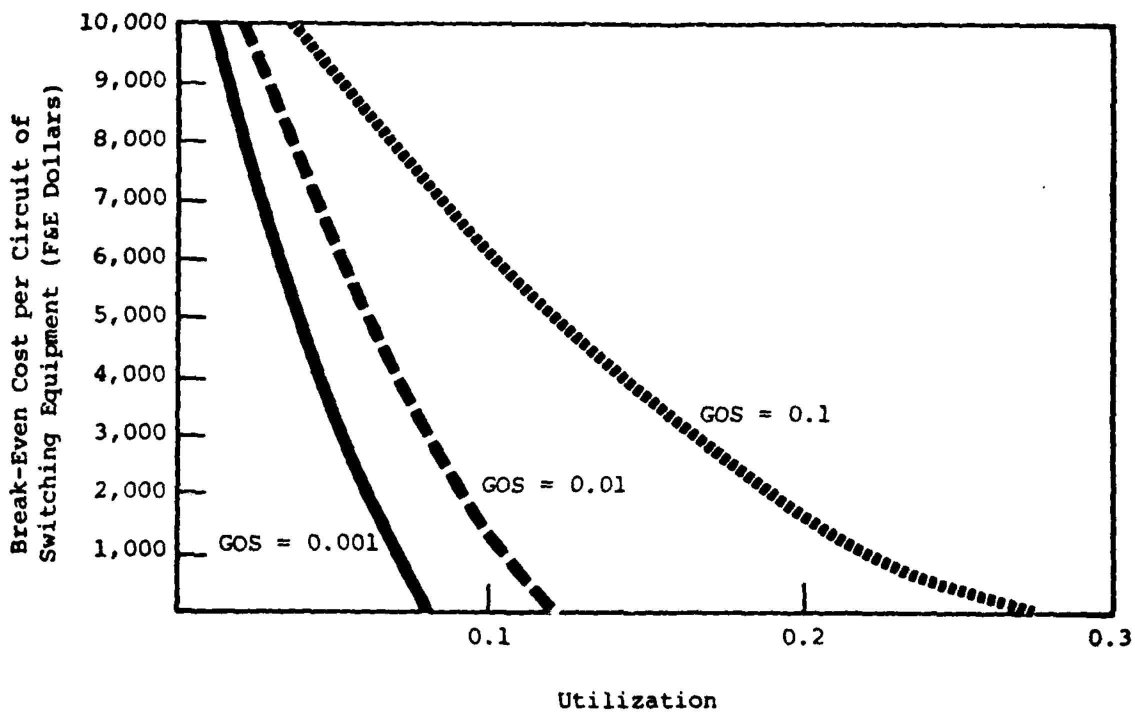


Figure 3-6. MAXIMUM EQUIPMENT COST VERSUS UTILIZATION

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*The present value of a payment of $1 per year for n years at interest rate r is $PV = \sum_{k=1}^{n} \left(\frac{1}{1+r}\right)^k$. For r = 0.1 and n = 10, $\sum_{k=1}^{10} \left(\frac{1}{1+r}\right)^k = 6.146$. The annual payment is 1/6.146 = 0.1627.

For intermediate utilizations, feasibility is quite sensitive to required grade-of-service and less sensitive to switch cost. Within this range, even if the operating point were within the bounds of economic feasibility, savings would be sensitive to the accuracy of parameter estimates. Relatively modest traffic growth, for example, could quickly eliminate any potential savings.

3.6 ESTIMATE OF CURRENT PARAMETER VALUES

In this section estimates of average utilization, grade-of-service, and equipment cost are provided. From these it will be possible to identify the point in Figure 3-6 where the current system is estimated to be and thereby to assess the economic feasibility of switching.

Estimates of peak-hour circuit utilization have been developed in the course of building the communications model. They were estimated from data on traffic handled at a sample facility and average call holding times. These are presented in Table 3-4. The mean of these utilizations, weighted by the number of circuits of each type, is 0.096. The estimates are assumed to represent the average utilization for a circuit group during the busiest hour of each day. It is assumed that the network would be designed on that basis.

Required grades-of-service will vary, depending on the function of the circuit. Since traffic of all priorities will be carried on the same circuit, the most stringent value for grade-of-service was selected for all circuits: the value of 0.001.

Switch costs for a moderate-to-large facility were estimated at $500 capital plus $30 a year for maintenance on each switch. The $30 a year must be converted to a capital cost to be compatible with Figure 3-6. If the .1627 factor from Section 3.5 is applied and the result added to the $500 figure, an up-front equipment cost of $684 will be obtained.

Table 3-4. ESTIMATED BUSY-HOUR VOICE CIRCUIT UTILIZATION

Circuit Category	Number of Circuits	Estimated Utilization
Miscellaneous	1487	0.08
FSS-Center	175	0.05
FSS-Tower	102	0.05
Tower-Center	603	0.05
Center-Center	274	0.10
Foreign Exchange	1421	0.12

Thus, the current operating point in Figure 3-6 is (0.096, 684). This lies between the curves for 0.01 and 0.001 grades-of-service. For the values selected, switching does not quite break even; for slightly higher values of grade-of-service or lower values of circuit utilization, the savings would be positive. This is an indication of the sensitivity to these parameters. On the other hand, switching equipment cost could rise as high as $2,000 to $3,000 per circuit before this variable would have a significant impact on feasibility.

For data circuits, the multiplexing costs would have to be subtracted from the gross savings of $390,000 per year. Utilization and grade-of-service criteria do not enter into the analysis, because data circuits are not switched. Assuming that multiplexing costs per circuit are comparable to those of switching, an amortized cost for auxiliary equipment of $135 per year will be required. This reduces the possible savings by $135 x 1028 circuits, or $139,000. Estimated savings are therefore $251,000 per year.

CHAPTER FOUR

SCENARIOS

4.1 INTRODUCTION

The National Airspace System (NAS) is not expected to remain static in the 1980s; rather it will evolve to accommodate the growth of air traffic. Existing systems will be expanded for this purpose, and new systems will appear that will exploit state-of-the-art improvements in communications hardware. The circuit network will be affected by these changes as well. Continuing automation of air traffic control should reduce the number of controllers required per aircraft and consequently reduce the need for voice circuitry.

A baseline case (i.e., the present communications system expanded to accommodate future traffic) is developed to provide a point of reference with which the costs of the alternatives can be compared. Factors such as aircraft traffic growth, IFR operations, surveillance expansion, increase in the number of FAA-operated airports, and regulatory reforms are applied on an equal basis to the baseline case. Because only communications-oriented facilities are included in the model, the output of the baseline will not necessarily correspond to the budget forecast. The baseline is intended to provide a reference point only.

The model has the capability of calculating communications cost by assigning a percentage to each facility that indicates the proportional cost of that facility allocated to communications. For the scenarios described in this chapter, we set all these percentages at 100 percent so that the model would calculate the total facility cost. Since the model does not include cost for air traffic (AT) personnel, the results developed here do not constitute a full life-cycle-cost analysis.

4.2 BASELINE SCENARIO

The baseline scenario represents continued operation of the present FAA communications system without modernization or other modification of any of the communications facilities. However, the baseline scenario does include expansion of the present system to handle the forecast growth in aircraft traffic. It is assumed that traffic growth will make it necessary to expand FAA facilities in number or size (or both), and to increase the size and complexity of the communications network.

The present implementation of the model has data for 64 separate types of facilities supporting communications. Growth in the number and size of these facilities is closely tied to that of sectors, radars, towers, centers, and flight service stations. These five kinds of facilities are referred to as operational units. Increases in FAA operational units will necessitate increases in many supporting communications facilities. In the baseline scenario, it is assumed that the present ratio of communications facilities to operational units will be maintained, so that the growth in facilities will be directly proportional to the growth in operational units. The growth in operational units is related to the forecast growth in aircraft traffic. The equations describing these relationships may be found in the companion report *FAA Communications Cost Model Program Documentation*. It should be kept in mind that the absolute accuracy of the projected costs in the baseline system will be dependent on the extrapolations. However, the relative accuracy of the cost differences between the baseline and the alternative scenarios will be much less affected by the absolute accuracy of the extrapolations because these extrapolations will be included in all scenarios.

The assumptions used in the baseline for inflation and discounting were also used in all other scenarios. Long-term inflation rates of eight percent for F&E and O&M costs and five percent for circuits were assumed. Historically, the rate of inflation for leased circuits has been consistently lower than that for F&E and O&M, which in turn has been indicative of that of the overall economy. Since current inflation rates (1979-1980) are higher than this, a gradual decline to the long-term rates was programmed into each scenario. The discount rate is a value-of-capital factor. According to guidelines set by the Office of Management and Budget (OMB), it represents the real rate of return of private investment before taxes and should be set at 10 percent. Since the model applies the discount rate to current rather than constant dollars, a long-term inflation-adjusted discount rate of 18 percent was used. The inflation-adjusted discount rate is calculated by adding 10 percent to the average of the F&E and O&M inflation rates. Table 4-1 shows the inflation rates used for F&E, O&M, circuits, and discounting; they are consistent with the OMB guidelines.

Table 4-1. INFLATION AND DISCOUNT RATES					
Year	Inflation Rates (percent)			Discount Rate	Inflation-Adjusted Discount Rate
	F&E	O&M	Circuits		
1979	11	13	8	10	22
1980	9	11	7	10	20
1981	8	10	6	10	19
1982	8	8	5	10	18
1983-1990	8	8	5	10	18

4.3 BASELINE WITH CIRCUIT SWITCHING

This scenario is identical to the baseline case except that most voice and data circuit groups are switched through the nearest center. Radio circuits are not switched, however.

The scenario for circuits is much the same as the one described in Chapter Three. Since the communications model works with circuit groups rather than individual circuits, the results will not be as precise as the detailed switching algorithm. Nevertheless, this run is important to establish a basis for comparison with other switching scenarios involving the new technology systems, scenarios which cannot be analyzed with the detailed algorithm.

In addition, the methodology used for data circuits is somewhat different from that described in Section 3.4. Since no bits-per-second information was available to the communications model and since circuit savings were comparable on a percentage basis for both voice and data, the switching algorithms were used for both the voice and the data networks.

4.4 BASELINE WITH 50 PERCENT INCREASE IN TRAFFIC

The objective of this scenario is to measure the cost impact of an increase in traffic over currently forecasted levels. All parameters are identical to those of the base case except for the traffic parameter, which is set at 1.5. This means that for any given year, the percentage growth in traffic is 50 percent higher than in the standard FAA forecast (e.g., 6 percent instead of 4 percent). The additional traffic should increase the operational units required, which in turn should increase F&E, O&M, and circuit costs. A comparison of this run and the baseline will show the sensitivity of all four major cost categories to traffic parameters.

CHAPTER FIVE

SCENARIO RESULTS

5.1 INTRODUCTION

Costs associated with the scenarios described in Chapter Four have been evaluated by means of the communications cost model. The model takes into account both the present communications facilities and the impact of changes to the configuration of FAA facilities. The results are developed separately for four cost categories. The first category consists of investment in facilities and equipment as a result of expanded service to meet user demand or as a result of new services associated with the alternative scenarios. The second category comprises operations and maintenance costs associated with existing and new FAA facilities. Finally, there are two categories of lease costs, telephone circuits and leased equipment. The total annual cost of FAA communications is computed as the sum of these costs.

The analyses described in this chapter are performed in current-year dollars, on the assumption of the inflation rates documented in Section 4.2. Most comparisons are made relative to the baseline scenario in order to determine which of the cost categories are affected by the scenario and which are the sensitive variables. The focus of this analysis is the impact on the circuit network, which is expressed in terms of leased circuit and leased equipment costs. F&E and O&M costs are considered only in the context of the scenario being run. However, since the model does not include most air traffic costs or savings, the results in this chapter do not represent a life-cycle-cost analysis.

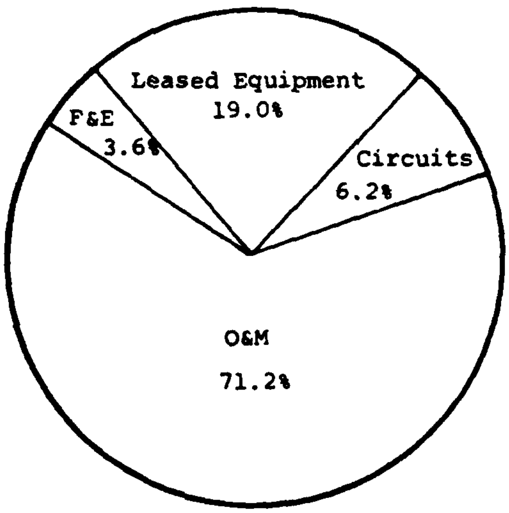
5.2 BASELINE EVALUATION

Table 5-1 shows the results of the baseline run. The growth in the volume of services provided by FAA facilities in response to aircraft traffic increases has resulted in a steady increase in all four categories of cost: facilities and equipment (F&E), operations and maintenance (O&M), leased circuits, and leased equipment. The F&E and O&M columns reflect costs of communications facilities within the NAS. Circuit costs are expenditures on leased private telephone lines, and leased equipment comprises all other leased services, such as key systems and switches. The F&E column in the companion tables includes investment in equipment needed to maintain growth of the ATC system and capital expenditures on new-technology equipment. Since the latter does not exist in the baseline, the F&E values in this particular table reflect growth alone.

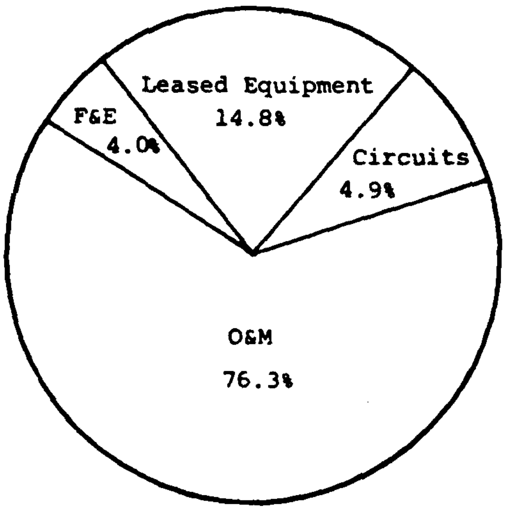
Table 5-1. BASELINE

COSTS BY CATEGORY-ALL AMOUNTS IN MILLIONS OF DOLLARS

YEAR		FACILITIES AND EQUIPMENT		OPERATIONS AND MAINTENANCE		CIRCUITS		LEASED EQUIPMENT		USER-ASSIGNED		TOTAL		NET PRESENT VALUE		CUMULATIVE NET PRESENT VALUE
1980	$	12.8	$	254.1	$	22.1	$	67.6	$	0.0	$	356.6	$	297.2	$	297.2
1981	$	13.9	$	281.3	$	23.6	$	72.0	$	0.0	$	390.8	$	273.7	$	570.8
1982	$	15.2	$	305.8	$	24.9	$	75.9	$	0.0	$	421.7	$	250.3	$	821.1
1983	$	16.6	$	332.4	$	26.3	$	79.9	$	0.0	$	455.2	$	228.9	$	1050.1
1984	$	18.1	$	361.3	$	27.8	$	84.2	$	0.0	$	491.4	$	209.4	$	1259.5
1985	$	19.8	$	392.6	$	29.3	$	88.8	$	0.0	$	530.6	$	191.6	$	1451.1
1986	$	21.7	$	426.7	$	31.0	•	93.5	$	0.0	$	572.9	$	175.4	$	1626.5
1987	$	23.8	$	463.7	$	32.7	$	98.5	$	0.0	$	618.8	$	160.5	$	1787.0
1988	$	26.1	$	504.0	$	34.5	$	103.8	$	0.0	$	668.4	$	146.9	$	1934.0
1989	$	28.7	$	547.7	$	36.4	$	108.3	$	0.0	$	722.1	$	134.5	$	2068.5
1990	$	31.5	$	595.2	$	38.4	$	115.2	$	0.0	$	780.3	$	123.2	$	2191.7



Communications Cost
Allocation in 1980



Communications Cost
Allocation in 1990

Figure 5-1. COMPARISON OF COST CATEGORIES: 1980 AND 1990

Figure 5-1 presents a comparison of the cost categories in 1980 and 1990 to indicate the distribution of costs. The predominant category by far is O&M, which accounts for 71.2 percent of the total costs in 1980 and 76.3 percent in 1990. The O&M costs are based on existing expenditures by facility type and on facility staffing standards developed by the FAA Airways Facilities Sector Level Staffing Standard Branch. The contribution of each of the 64 facilities to overall O&M costs varies substantially: The top five facilities -- RCO, towers, Automated Radar Terminal System (ARTS), FSS, and RCAG -- account for about 53 percent of reported O&M costs.

When the inflation factor is removed from the F&E and O&M costs, real growth is found to be only 14 percent for F&E and 8.5 percent for O&M in spite of a predicted 40 percent increase in IFR aircraft handled, because of the slow growth of many of the operational units. The number of ARTCCs and the number of FSSs are constant, and only two new towers a year are to be commissioned. The only major operational variable that is unconstrained is sectors.

Circuit and leased equipment costs show a smaller share of the total cost, mostly because the inflation rate for communications services has historically been lower than the average inflation rate. Real growth in circuit and leased equipment costs over the decade are estimated at 6.7 percent and 4.6 percent, respectively. Like the F&E costs, the growth in circuits is held down by the constraints on the growth of operational units. It should be noted that the only circuits considered in the evaluation are those which must be leased from common carriers on an annual basis. Those associated with terminal operations (e.g., airport property supporting RTRs, ILSs, and ASRs) are assumed to be provided by the municipal authority and not subject to annual federal expenditures. Circuits required in support of air traffic control affect tower, center, and FSS operations, and normally are leased from industry. The combined total circuit mileage of voice, data, and radio circuits in 1979 was about 1.52 million miles. Because of the growth in FAA operations that is expected to be necessary to provide the 1979 quality of service during the next decade, the total circuit mileage in 1990 is expected to grow modestly to 1.60 million miles. The data are based on the existing average length for each of the three types of service.

5.3 BASELINE WITH VOICE AND DATA CIRCUITS SWITCHED

This scenario is the same as the baseline except that underutilized voice and data circuits can be switched through the centers in an effort to reduce circuit costs. A detailed discussion of the algorithms used in this process may be found in Chapter Two of this report and in *FAA Communications Cost Model Program Documentation*. Switching as discussed here should not be confused with VSCS: Circuit switching will not be accomplished through VSCS until at least 1990; further, VSCS will provide a number of capabilities besides switching. Switching here refers only to equipment that can select an available circuit over which to route a call. In the current system, there is no switching in this sense because there is a dedicated line between each pair of points.

The results for this run are shown in Table 5-7; Figure 5-7 shows the variations relative to the baseline. The major change appears in the circuits column, which shows a saving of $4.7 million on leased circuit expenses in 1980.

Table 5-8 shows the circuit categories to which the switching algorithm was applied. When the circuits are switched, traffic from categories that do not pass through a center (e.g., category 2, FSS-tower voice circuits) is rerouted through the nearest center by adding that traffic to the appropriate categories that do pass through the center (in this case, category 3, FSS-to-center, and category 4, tower-to-center). For most of the data categories, the number of circuits remains unchanged in spite of switching, because of the limits placed on the number of circuits required. If the number of circuits required for switching is greater than the number of dedicated lines in place, switching is rejected.

Where switching is feasible (see Table 5-7), F&E and O&M costs are added for the switching equipment. In the first year only, the F&E cost for switching equipment is a one-time expenditure of $2.0 million. The O&M cost appears every year but amounts to $300,000 or less per year.

Savings from circuit switching may be observed by subtracting results in Table 5-7 from those in the baseline in Table 5-1. Circuit switching for voice and data appears to be feasible, but not overwhelmingly so. Savings of $4.7 million in 1980, or 21 percent of the total expense, are forecast by the model. This ratio remains fairly stable over the entire decade. In present-value terms, savings of $23.1 million over the decade are expected. The savings are split between reductions in the number of terminations and

Table 5-7. BASELINE WITH CIRCUIT SWITCHING

COSTS BY CATEGORY-ALL AMOUNTS IN MILLIONS OF DOLLARS

YEAR	FACILITIES AND EQUIPMENT	OPERATIONS AND MAINTENANCE	CIRCUITS	LEASED EQUIPMENT	USER-ASSIGNED	TOTAL	NET PRESENT VALUE	CUMULATIVE NET PRESENT VALUE
1980	$ 14.8	$ 254.2	$ 17.4	$ 67.6	$ 0.0	$ 354.0	$ 295.0	$ 295.0
1981	$ 13.9	$ 281.5	$ 18.6	$ 72.0	$ 0.0	$ 386.0	$ 270.3	$ 565.3
1982	$ 15.2	$ 305.9	$ 19.7	$ 75.9	$ 0.0	$ 418.7	$ 247.3	$ 812.6
1983	$ 16.6	$ 332.5	$ 20.8	$ 79.9	$ 0.0	$ 449.9	$ 226.3	$ 1038.9
1984	$ 18.1	$ 361.4	$ 22.0	$ 84.2	$ 0.0	$ 485.9	$ 207.1	$ 1246.0
1985	$ 19.8	$ 392.8	$ 23.3	$ 88.9	$ 0.0	$ 524.7	$ 189.5	$ 1435.5
1986	$ 21.7	$ 426.9	$ 24.7	$ 93.5	$ 0.0	$ 566.8	$ 173.5	$ 1609.0
1987	$ 23.8	$ 463.9	$ 26.1	$ 98.5	$ 0.0	$ 612.4	$ 158.8	$ 1767.8
1988	$ 26.1	$ 504.2	$ 27.5	$ 103.8	$ 0.0	$ 661.7	$ 145.5	$ 1913.3
1989	$ 28.7	$ 547.9	$ 29.1	$ 109.3	$ 0.0	$ 715.1	$ 133.2	$ 2046.5
1990	$ 31.5	$ 595.5	$ 30.7	$ 115.2	$ 0.0	$ 772.9	$ 122.0	$ 2168.5

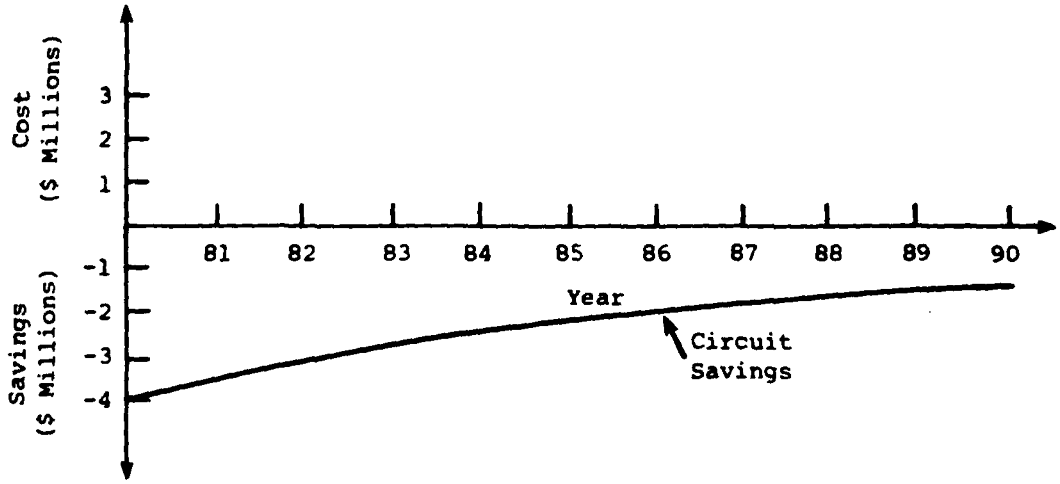


Figure 5-7. ANNUAL DISCOUNTED CIRCUIT SAVINGS OF SWITCHING RELATIVE TO BASELINE

Table 5-8. COMPARISON OF SWITCHED AND NONSWITCHED CIRCUITS				
Circuit Category	Baseline Parameters			
	Number of Circuits		Circuit Mileage	
	Nonswitched	Switched	Nonswitched	Switched
Miscellaneous Voice	1,487	599	211,035	85,023
FSS-to-Tower Voice	175	0	13,143	0
FSS-to-Center Voice	101	1,188	26,182	305,860
Tower-to-Center Voice	603	778	90,087	116,282
Center-to-Center Voice	273	112	119,274	48,827
FSS-to-Public Voice	1,420	0	61,859	0
Miscellaneous Data	947	205	432,741	93,692
FSS-to-Tower Data	0	0	0	0
FSS-to-Center Data	28	28	15,528	15,528
Tower-to-Center Data	239	239	27,074	27,074
Center-to-Center Data	94	94	47,529	47,529

reductions in circuit mileage. This split contrasts with the analysis presented in Chapter Three, where almost 100 percent of the savings is in the reduced number of terminations. The communications model does not have an algorithm for adjusting average circuit mileage as a result of switching; therefore, the predicted circuit mileage savings forecast are likely to be somewhat high. The predicted $2.4 million savings from terminations compare favorably with those from Chapter Three for the utilization and grade-of-service specified.

5.4 BASELINE WITH 50 PERCENT INCREASE IN TRAFFIC

The case of the baseline with 50 percent increase in traffic is the same as the baseline except that the yearly percentage increase in traffic is 50 percent higher than that of the baseline. Results of this scenario are shown in Table 5-9; a plot of the cost variations relative to the baseline is shown in Figure 5-8.

Because of the anticipated slow growth in operational units (other than sectors), costs are not very sensitive to traffic growth. With the number of towers, centers, and FSSs remaining fairly constant, the major area of growth is the sector area. This growth will necessitate some additional center-to-center voice and data circuits and center-to-RCAG radio circuits. The net effect is about 300 circuits more than the baseline. In terms of net present value, the effect of this booming traffic scenario is an increase of only about $21 million over the baseline figure by 1990, less than 1 percent of the projected cumulative expenditure of $2.19 billion.

Table 5-9. BASELINE WITH 50 PERCENT INCREASE IN TRAFFIC

COSTS BY CATEGORY-ALL AMOUNTS IN MILLIONS OF DOLLARS

YEAR	FACILITIES AND EQUIPMENT	OPERATIONS AND MAINTENANCE	CIRCUITS	LEASED EQUIPMENT	USER-ASSIGNED	TOTAL	NET PRESENT VALUE	CUMULATIVE NET PRESENT VALUE
1980	$ 14.1	$ 255.0	$ 22.2	$ 67.8	$ 0.0	$ 359.1	$ 299.3	$ 299.3
1981	$ 15.3	$ 282.7	$ 23.7	$ 72.2	$ 0.0	$ 393.9	$ 275.8	$ 575.1
1982	$ 16.5	$ 307.6	$ 25.1	$ 76.2	$ 0.0	$ 425.3	$ 252.4	$ 827.5
1983	$ 17.9	$ 334.6	$ 26.6	$ 80.3	$ 0.0	$ 459.4	$ 231.0	$ 1058.5
1984	$ 19.4	$ 364.0	$ 28.1	$ 84.7	$ 0.0	$ 496.2	$ 211.5	$ 1270.0
1985	$ 21.1	$ 395.9	$ 29.7	$ 89.3	$ 0.0	$ 536.0	$ 192.8	$ 1462.8
1986	$ 23.0	$ 430.6	$ 31.4	$ 94.1	$ 0.0	$ 579.1	$ 177.3	$ 1640.9
1987	$ 25.1	$ 468.2	$ 33.2	$ 99.2	$ 0.0	$ 625.7	$ 162.5	$ 1803.2
1988	$ 27.4	$ 509.1	$ 35.0	$ 104.6	$ 0.0	$ 676.2	$ 148.6	$ 1951.8
1989	$ 30.0	$ 553.6	$ 37.0	$ 110.2	$ 0.0	$ 730.8	$ 136.1	$ 2088.0
1990	$ 32.8	$ 601.9	$ 39.1	$ 116.1	$ 0.0	$ 789.9	$ 124.7	$ 2212.7

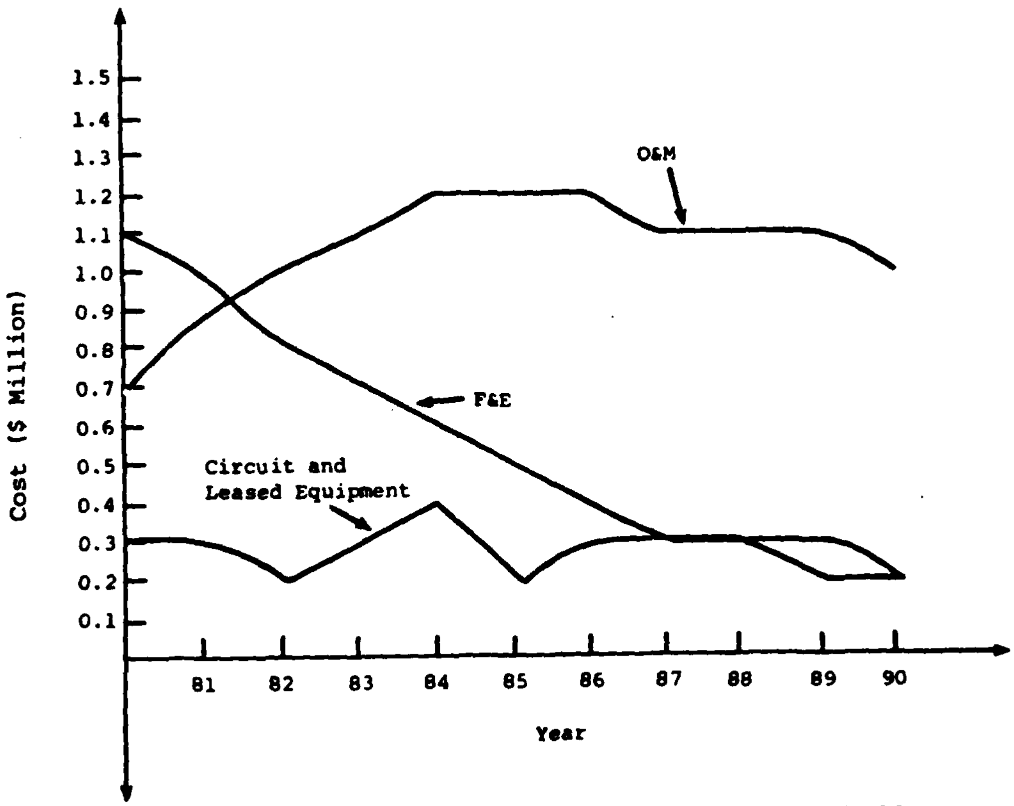


Figure 5-8. ANNUAL INCREASE IN COST RELATIVE TO BASELINE RESULTING FROM 50 PERCENT GROWTH IN TRAFFIC

CHAPTER SIX

CONCLUSIONS

The preceding chapters developed a cost analysis of switching and non-switching in FAA voice and data circuit networks. The analysis assumed network configuration where circuits were switched through the 20 continental ARTCCs.

Switching underutilized circuits would mean the procurement of additional equipment to sense demand for service, search for an idle circuit and switch to it, and route the call properly at the other end. This equipment must be installed at points convenient to all other network nodes, because all traffic will be switched through these points. If the economies of scale that switching offers are to be fully exploited, the equipment probably should be located in the 20 continental U.S. air route traffic control centers (ARTCCs), and our switching algorithm is based on this assumption.

On a cost basis alone, circuit switching in the current network configuration promises only marginal gain. According to estimates of current parameter values for utilization, required grade-of-service, and switching equipment cost, the switching plan described here would not quite break even given a 10-year equipment life and would do slightly better given a 15-year life. Optimization of the resulting network by the introduction of other benefits would probably change the economics to the plus side; unfavorable estimates of the parameters, or changes in conditions, could make switching an economic loss. The feasibility is sensitive to utilization and grade-of-service over the current operating range; it is less sensitive to equipment cost. Because of these sensitivities to various parameters, it appears that from a strictly economic viewpoint, circuit switching does not provide a major benefit to the FAA under the network configurations analyzed. When firm data on circuit utilization and grade-of-service become available, it will be appropriate to reassess this issue.

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